The Future of Lithium-ion Space Batteries: A Supplier's Perspective

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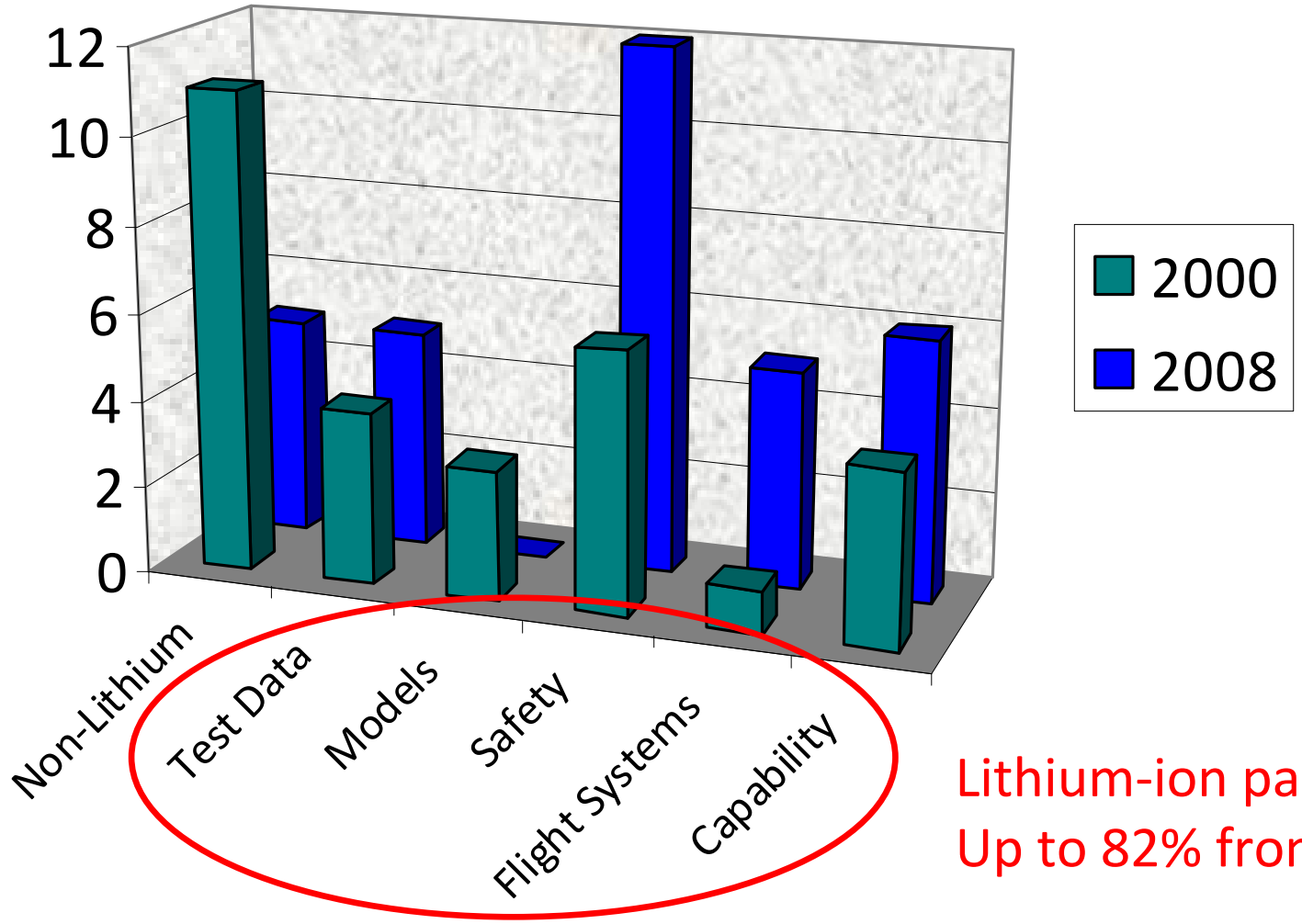
Lithium-ion: The Preferred Technology

ABSL SPACE PRODUCTS

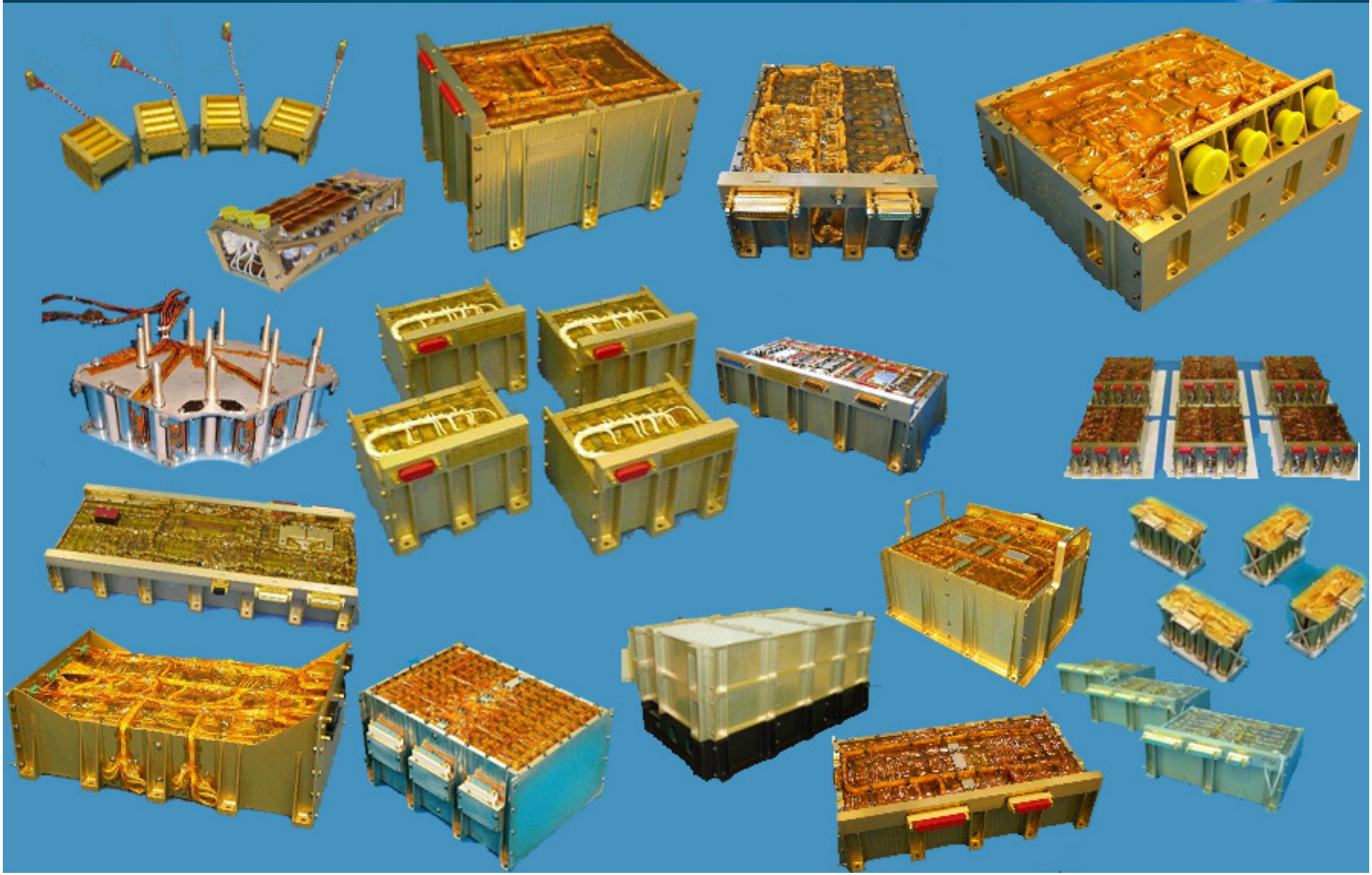
NBW Papers 2000 and 2008:



Lithium-ion papers
Up to 82% from 62%

For All Applications

ABSL
SPACE PRODUCTS



The Next Space Chemistry?

	30Wh/kg		60Wh/kg		120Wh/kg	
TECHNOLOGY						
JUMP	NiCd	→	NiH2	→	Li-ion	→ ?
ENVIRONMENTAL						
PUSH	✗		✗		?	

- Incremental developments of each technology but …

  … it is environmental factors drive the technology jumps

- Which environmental factor will cause the next jump?
- As important to understand that as it is chemistry advances …

How many suppliers?

Specialist space batteries vendors selling to USA:

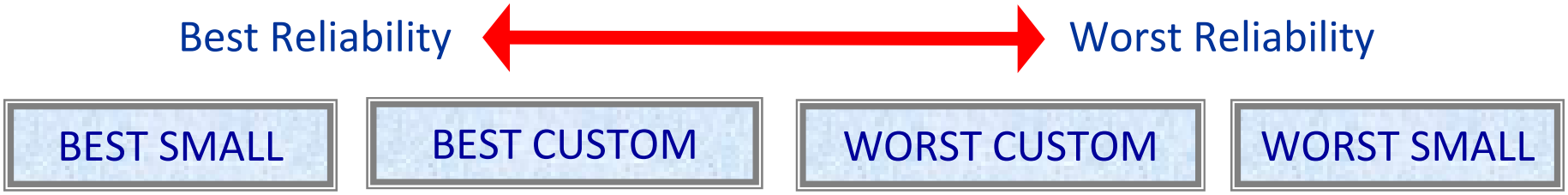
- NiCd — two + Prime DIYs
- NiH_2 — two/three + Prime DIYs
- Current Li-ion — five + smaller ones + fewer Prime DIYs

- Market size increasing? Not by a factor of 2/3.
- Current revenues of biggest five companies: c. $100m p.a.
- Sustainable competitive environment? Probably not.

CONSOLIDATION / WITHDRAWAL INEVITABLE?

Most reliable approach?

Custom Space Cell Approach	ABSL Small Cell Approach
Space qualified processes	Smaller cells easier?
Source inspection	LAT / screening?
x12 to x333 better?	Quality learning curve
Less interconnections	Less electronics
	Battery redundancy



- Greater variability between supplier than between approach
- Will never have enough data to prove or disprove this

FITs in context

Space component FIT rates (random failure rates – not wear-out rates):

Capacitor: 0.1-10

NiH_2: cell circa 200

Li-ion cell: 5-500

- NOTE: 5 – 500 FIT = MTBF 2 to 200 million hours
- Largest cell life-test database (ABSL) only 141 million cell-hours!!!

- Mathematical fact:
  - Large custom space cells are often assigned a FIT rate of 200
  - We have been building and testing custom Li-ion for, say, ten years
  - Assuming there are less than one million custom cells on test (very likely)
  - Another ten years test needed before we can expect the first failure …

Reliability of commercial cells …

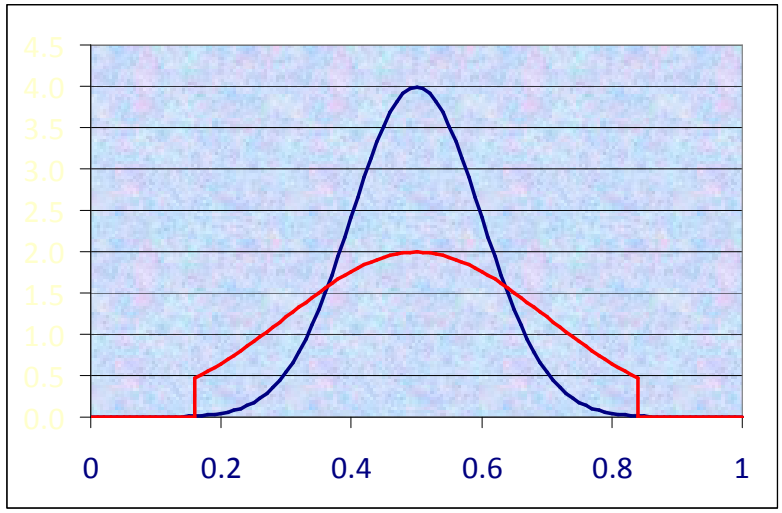
- Learning curves: Henderson, Levy (1965) Cost $X_n = K N^{-b}$
- Quality learning curves: Schneiderman (1988) $QI_n = (QI_n) N^{\pm m}$

Perspective:

Sony 41 million/month – whole space industry since 1957 in less than 2 days!

Does not mean that all high-volume cells are good quality …

- ABSL technology watch – 250 cells – found highly variable quality



Screen to improve quality?

✓ *to remove rogues/outliers*

✗ *to trim population*

- not the same as low σ (std dev)

- many cells at extremes

Reliability of Sony cells …

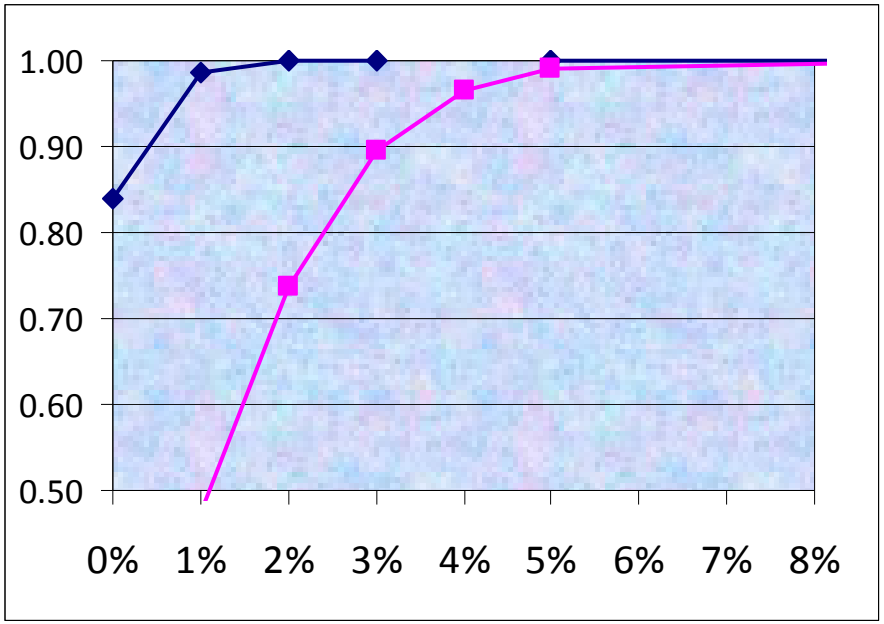
- Data for commercial product suggests better than single digit FIT
  - Then up-screen MIL-HBK-217 suggests x12 to x333 improvement
  - Figures very hard to believe – it is an incredible cell!!
- Lap-top incidents
  - 40 overheating incidents – 17 to 20 ‘smoke / flames’
  - Sony manufactured c. 4 billion cells at time of issue
  - Latest recall concerned product from a 260m production volume
  - Assume each has three years continuous operation (pessimistic)
  - Incident FIT between 0.00018 and 0.0059 best/worst-case

Perspective:

- For all 8,300 S/C since 1957, less than 2% probability of incident
- Custom space cells (of any type) could be at least x10^5 more susceptible and we would be unlikely to know it yet …

Reliability: a 'relative' science

Reliability as a function of %redundant strings



Comparative example:

Five-year mission

Eight cell strings

5 FIT – dark blue

50 FIT - pink

- Adding 5% redundant strings gives high reliability for low FIT cells
- Of course, can only add 5% spare if you have a battery with greater than 20 strings …

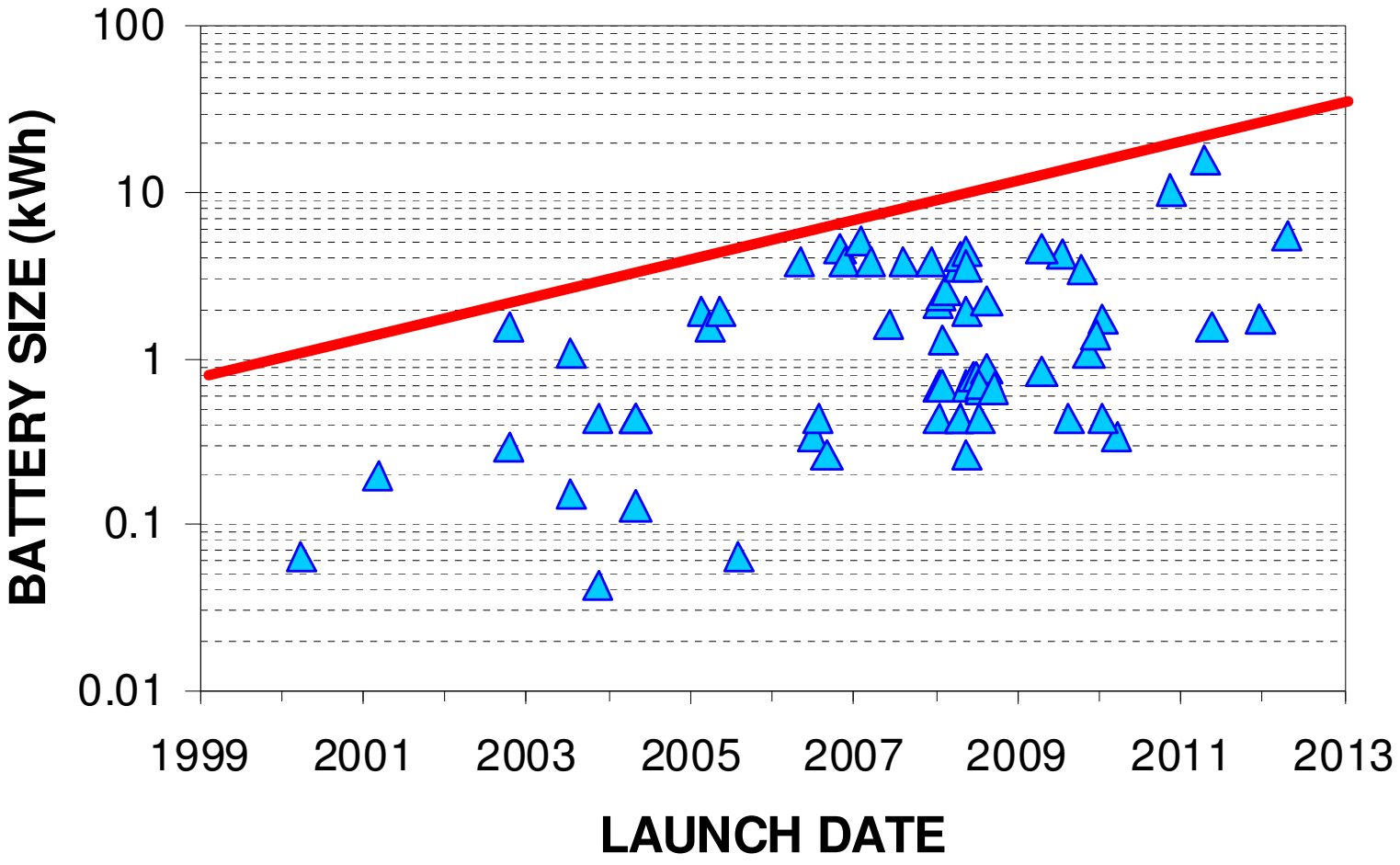
So, how big can you go …

- Always provokes strong opinions
- Many of the original ‘sceptics’ have now become ‘believers’
  - Stable arrays with 13.5 year LEO cycling (accelerated to 9 years)
  - Self discharge rate measurements on ten year old cells
- Engineering analysis or ‘common sense’?

“A collection of prejudices acquired during the course of your first two space programmes”

- For some engineers the number of interconnects is a concern
  - Same engineers use solar arrays with no issues
- My contention:
  - Small cell = smaller coil pack + more interconnects
  - Coil pack is a far high reliability challenge than an interconnect

‘Small’ is the new ‘Big’

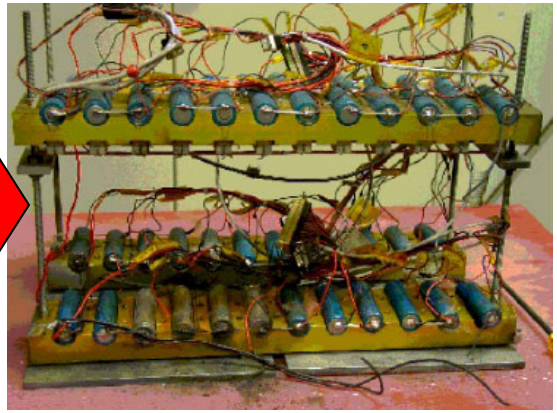


Safety – abuse and use

Overcharge

External Shorts

Protection Devices



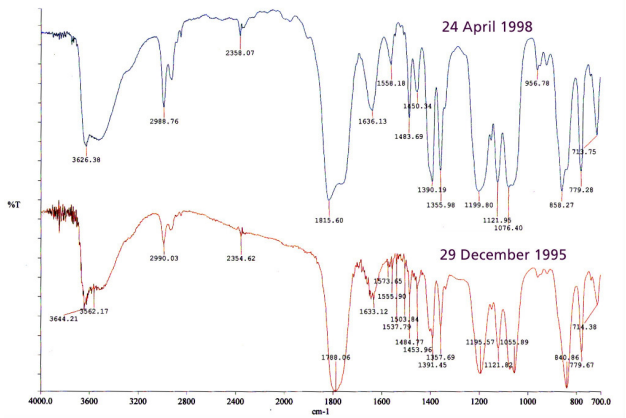
Abuse of COTS cells well characterised → engineering solutions

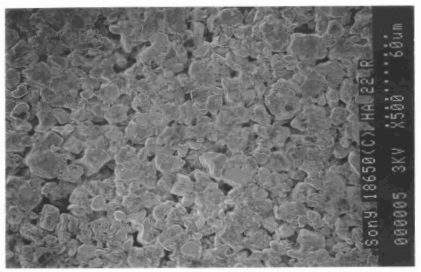
The current concern: internal shorts

- Difficult to characterise and even more difficult to engineer against
- Incidents are so very rare in commercial cells – acceptable risk?
- Improve risk: good quality cells, SMALL CELLS BETTER (c.f. TIAX analysis)
- Reality: thermal design protects against *some* shorts, further reduces risk

The 3rd party supplier dilemma…

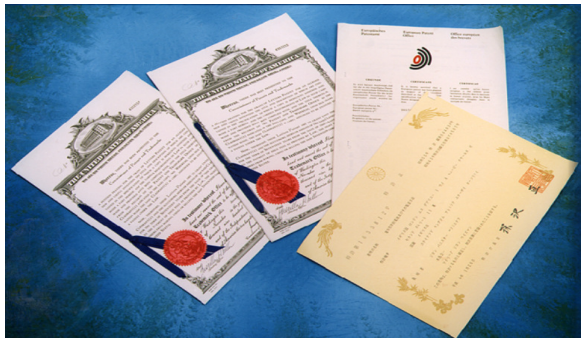
- Key issue is verifying cycle-life performance
  - ABSL life-test data set, multi-million $ investment
  - Rely upon LAT to read-across life test data
  - Need to detect very small changes in chemistry
- ABSL contend that a detailed LAT costs > $150k
- Alternative is to life-test each COTS batch before flight
  - Only practical for short missions (<one year?)





Supplier Relationships

- Confession: ABSL heritage solution its not *exactly* COTS
  - Commercial design standard manufactured to order for ABSL by Sony
  - Hence eye-watering price premium
  - But finance is not what incentivises Sony
- Must be non-financial driver for commercial supplier to work in Space
- Sony / ABSL – goes back to patents
- Impacts custom cells as well



Our conclusion:

ARM'S LENGTH RELATIONSHIP WITH COTS SUPPLIER IS VERY HIGH RISK

You'll get surprises in LAT or life-test that blow your investment

Should COTS be low-cost?

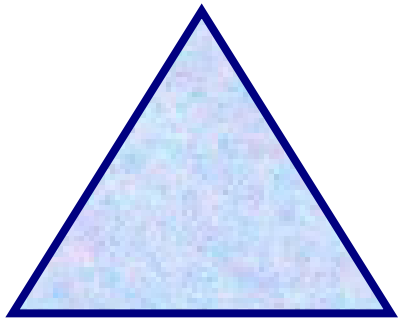
	'Traditional' Approach	'Small-Cell' Approach
Cell Cost	$$$	$
LAT	Not required	$$$
Screening	$	$$$
Battery assembly	$$	$$
Total	About the same	

- Small cell approach can provide low-cost if:
  - If mission is short, no hard reliability requirements
  - Then buy a COTS batch & life-test (but extensive life-test is not cheap)
- Significant cost driver is the nature of the customer not the approach
  - How many meetings, how much documentation, hand-holding, etc?

The Dichotomy of the Space Industry

High reliability	↔	Low volume
Latest performance	↔	Heritage
Low cost	↔	Custom manufacture
Security of supply	↔	Long-term, low-volume needs

Quality
(Hard to quantify)



Performance
(Poor return on investment)

Price
(Too many competitors)

Conclusions

- ABSL small cell OR custom space cell?

  Both work, all suppliers have a potential future. But it depends on ...

- … environmental factors above technical prowess, for example:
  - Political — ITAR, environmental regulations
  - Financial — Robustness to financial climate
  - Incidents — First major safety incident?
  - Technological — Other rechargeable battery markets
  - Security of supply — Easiest materials for low-vol / high rel

The problem with the future is that it is obsolete by the time you get there...